Available online at: http://www.ijmtst.com/vol5issue11.html
International Journal for Modern Trends in Science and Technology
ISSN: 2455-3778 :: Volume: 05, Issue No: 11, November 2019

A Survey of Key Performance Indicators for Generic Cellular Networks

N.S. Tarkaa[1] | C.A.D. Pahalson[2]

[1]Department of Electrical and Electronics Engineering, University of Agriculture, Makurdi, Nigeria
[2]Department of Electrical and Electronics Engineering, Plateau State Polytechnic, Barkin Ladi, Nigeria

To Cite this Article
N.S. Tarkaa and C.A.D. Pahalson, "A Survey of Key Performance Indicators for Generic Cellular Networks", *International Journal for Modern Trends in Science and Technology*, Vol. 05, Issue 11, November 2019, pp: 82-94.

Article Info
Received on 17-October-2019, Revised on 01-November-2019, Accepted on 04- November -2019, Published on 07-November-2019.

ABSTRACT

The increasing offer of advanced services in cellular networks forces operators to provide stringent quality of service (QoS) guarantees. The contentment level of different customers depends on different QoS levels based on key performance indicators (KPIs). Monitoring QoS of any telecommunications network requires continuous processes that estimate values of the KPIs in real-time that determine the quality of service rendered to the subscribers. System coverage, trunking efficiency, spectrum efficiency, carrier-to-interference ratio (C/I), drop-call probability and call blocking probability are some of the important KPIs used to estimate the performance of cellular networks. The system coverage in an area is dependent on the area covered by the signal. Trunking efficiency relates to the number of customers per channel to the number of channels per cell for a particular grade of service. Spectrum efficiency is a measure of how efficiently space, frequency and time are used. The C/I factor arises because wireless users communicate over the air and there is significant interference between them. Call dropping refers to the event described by the termination of calls in progress before either involved party intentionally ends the call. Blocking occurs when a base station has no free channel to allocate to a mobile user. In this paper, the KPIs' concepts are reviewed and presented in a more coherent and unified manner than have been previously done including the illustration of the concepts in an experimental context for an operative cellular network.

KEYWORDS: *Call blocking probability, Carrier-to-interference ratio, Drop-call probability, Spectrum efficiency, Trunking efficiency*

I. INTRODUCTION

The wireless nature of cellular communication networks creates interference among simultaneously communicating links or nodes in the network, resulting in performance degradation as the number of nodes in the network increases. The performance degradation affects the end users who depend on their personal communicating devices like mobile phones, iPads, laptops and many other devices which come with different features and capabilities for services like email, web browsing, audio and video streaming that demand a lot from the underlying network. If the network does not deliver what these services demand, the performance and the user satisfaction will be unsatisfactory. The contentment level of different customers depends on different quality of service (QoS) levels based on key performance indicators. Monitoring QoS of any telecommunication network requires continuous processes that estimate values of the KPI parameters in real-time from analysis of the measured empirical data that determines quality of service rendered to the subscribers. However, as the number of services and subscribers of cellular networks increases, the demand for good QoS has become a national issue which in Nigeria, for instance, the legislative body has ordered that the regulatory body, the National Communications Commission (NCC) to track and record dropped calls because of legislative concerns and debate [1]. There are many network parameters that evaluate the quality of delivered network services [2]. In wireless mobile networks, characteristics of cellular networks that determine the quality of performance are captured by different key performance indicators (KPIs) for the purposes of evaluation and monitoring. KPIs have been used in different ways to improve the performance of service providers and communication systems designers. They have been used as a corrective measure, fault monitoring tool in the development of high end communications infrastructure to meet acceptable standard of telecommunication regulatory bodies for users' satisfaction. Traditionally, wireless operators have used a number of metrics that collectively provide a measurement of network service quality for the users' perspective, but overall service quality will generally be determined by a combination of six KPIs that are of great importance. These are namely, System coverage, Trunking efficiency, Spectrum efficiency, Carrier-to-interference ratio (C/I), Call blocking probability (CBP) and Drop-call probability (DCP). The selected parameters are perceived to have direct impact to subscriber experiences on the network. The system coverage in an area is dependent on the area covered by the signal. Trunking efficiency relates to the number of customers per channel to the number of channels per cell for a particular blocking probability. Spectrum efficiency is a measure of how efficiently space, frequency and time are used. The C/I factor arises because wireless users communicate over the air and there is significant interference between them. Call dropping refers to the event described by the termination of calls in progress before either involved party intentionally ends the call. In the telecom world, performance measurement is usually defined in terms of accessibility (i.e., getting on the network), retainability (i.e., staying on the network) and connection quality or service integrity (i.e. having a good service experience while using the network), and finally the network coverage (i.e., the geographical region covered by one mast). There are different key performance indicators (KPIs) for different services and on different network layers. Therefore, it is useful for cellular network designers and service providers to have knowledge of the key performance indicators for the purpose of planning and optimizing the network usage and enhancing customer satisfaction [3]. Defining the KPIs are the most important part of the process because they relate to the methodology of optimization [4]. The KPI parameters are responsible directly for the coverage, capacity, and quality of the network. Following this, the network performance monitoring is required to ensure the user satisfaction. In [5], the different definitions and the various indices that underscore the concept of KPIs are given.

There are two fundamental aspects of wireless communications that generally impact the KPIs. First is the phenomenon of fading: the time variation of the channel strengths due to the small-scale effect of multipath fading, as well as larger-scale effects such as path-loss via distance attenuation and shadowing by obstacles. Secondly, wireless users communicate over the air and there is significant interference between them. In wireless networks, capacity variation arises from the mobility of users and the time-varying characteristics of the wireless propagation environment. The patterns of wireless interference for the active connections may dynamically change the available capacity for these connections. This underscores the importance attached to the use of path-loss models at the initial design stage of the network. The KPIs concepts abound generally in cellular communication literature in which they are presented in different ways usually disjointed, mixed up with sundry material. This paper aims to present the KPIs concepts in a more coherent and unified manner and to illustrate the concepts in an experimental context of an operative cellular network on which they have been applied.

The rest of the paper is organized as follows: The types of cellular networks are discussed in section 2. In section 3, the key performance indices for cellular networks are discussed. Experimental data analysis is presented in section 4. Lastly in section 5 is the conclusion.

II. TYPES OF CELLULAR NETWORKS

Cellular networks are now entering a new phase, driven by some major evolutionary trends. Mobile technologies such as Global System for Mobile Communications (GSM) have truly altered people's lifestyles and expectations all over the world. Since the advent of mobile communications, the technology has evolved independently in different countries, principally in Europe, North America and Japan. The different standards are based mainly on frequency spectrum, modulation techniques, multiple access methods, and speech compression techniques. Prominent among the different types of cellular systems that have evolved are Frequency Modulation (FM) based on the Advanced Mobile Phone Service (AMPS) of the USA; Analog/digital Frequency Division multiple access (FDMA); Digital narrow band Time Division Multiple Access (TDMA) that is standardized as GSM in Europe, as IS-95 system in North America and now developed as Code Division Multiple Access (CDMA) 2000IX by Qualcomm in the U.S.

The growth of cellular technologies worldwide over the last few years has been phenomenal. About five billion people currently use wireless services. The development of cellular technologies is commonly categorized into various generations. The cellular wireless Generation (G) generally refers to a change in the nature of the system, speed, technology and frequency. The First-Generation GSM system also known as the 1G is an analogue based system which makes provision for basic voice, short message services (SMS) and circuit switch data, yet its quality is poor in addition to its inability to handle growing capacity needs [6]. Thus, improving the QoS became a major consideration in the second and third generation cellular networks christened 2G and 3G respectively. The 2G networks were unable to provide better and fast data services, thus, the 3G systems are being employed to mitigate this setback and to provide a variety of data services such as internet browsing, e-mails, video telephone, and video streaming, while satisfying more stringent availability and QoS requirements in all types of environments [7]. Currently, both 2G and 3G cellular network have become operational in most countries.

As the underlying wireless technologies continued to evolve, they supported more robust broadband data services and applications, in addition to mobile voice communication services. In recent years, new wireless technologies have been introduced that focus on both fixed and mobile broadband data services. Fourth generation (4G) refers to International Mobile Telecommunications Advanced (IMT-Advanced), as defined by ITU-R [8], are also on the horizon that will provide broadband wireless access with asymmetric bit rates that approach 1 Gb/s [9].

In the world today, two 4G candidate systems are commercially deployed: The Mobile worldwide interoperability for microwave access (WiMAX) standard (at first in South Korea in 2006), and the first-release Long Term Evolution (LTE) standard (in Oslo, Norway since 2009). LTE, boasts of the following characteristics (3G Americas): Much improved user experience, Reduction of operation expenditure (OPEX) and capital expenditure (CAPEX), improved spectral efficiency, scalability of the frequency band and maximized reuse of the infrastructure. The ITU on December 6, 2010, stated in a press release that it accepted the use of the 4G term for systems that provided a substantial level of improvement in performance and capabilities over initial 3G systems.

III. KEY PERFORMANCE INDICES FOR CELLULAR NETWORKS

In wireless mobile networks, characteristics of cellular networks that determine the quality of performance are captured by the KPIs for the purposes of evaluation and monitoring. Performance indicators for cellular network services include but are not limited to the following: system coverage, trunking efficiency, spectrum efficiency, carrier-to-interference ratio (C/I), call blocking probability, and drop-call probability. The selected parameters are perceived to have direct impact to subscriber experiences on the network. In the telecom world, performance measurement is usually defined in terms of accessibility (i.e., getting on the network), retainability (i.e., staying on the network) and connection quality or service integrity (i.e. having a good service experience while using the network), and finally the network coverage (i.e., the geographical region covered by one mast). An overview of the key performance indices for cellular networks is given in the following paragraphs.

Trunking efficiency

Trunking is the second concept that made mobile cellular telecommunication systems possible to provide efficient and cost effective service to users. It is commonly used in very high frequency radio telecommunication systems [10]. In order to utilize the available spectrum and radio equipment efficiently, cellular network systems depend on trunking to accommodate a large number of subscribers in a limited number of channels. A trunked radio system is a system in which many users share the use of a common pool of radio channels. Channels are assigned on demand for the duration of a call and, as calls are completed, the channels are returned to the pool for assignment to other users. The important principle behind this concept is that any user has access to any free channel within the pool giving temporary exclusive use of a channel. This has the advantage that more mobiles per channel can be accommodated for a given grade of service, resulting in an overall improvement in spectrum efficiency when compared with an equivalent number of single channel systems. Trunking exploits the statistical behavior of users so that a fixed number of channels or circuits may accommodate a large number of users. Some of the important factors to be taken into consideration are: Service statistics, Number of Servers/Channels and Arrival statistics [11].

Trunking efficiency is defined in [12] as a measure of efficiency for a trunked system is the maximum traffic intensity that is carried by the system subject to a given GoS. Since the total traffic is obviously a function of the number of channels, we usually need to explain clearly the context within which we define the trunking efficiency. For example, for a cellular system with a fixed total number of assigned channels N, different N will result in different channels per cell therefore different trunking efficiency per cell. First, the total number of channels increases due to the frequency reuse. Second, for a given cellular system, different channel assignment scheme will result in different trunking efficiency. For example, dynamic channel assignment, i.e., channels are assigned dynamically in accordance with user traffic, has better trunking efficiency than fixed channel assignment scheme. On the other hand, sectoring, aimed to decrease the co-channel interference, will indeed decrease trunking efficiency. Trunking efficiency is given as:

$$(\eta_T) = \frac{\text{Carried traffic in Erlangs}}{\text{number of channels}} \quad (1)$$

Trunking efficiency is also measured by the channel usage efficiency (or loading factor) [13]. The channel utilization depends on the total traffic and call arrival rate. In the Erlang B model:

$$\eta_T = \frac{P(1-P_B)}{N} \text{ Erlang/channel} \quad (2)$$

The blocking probability, P_B is obtained from the Erlang-B formula as:

$$P_B = \frac{\frac{P^N}{N!}}{\sum_K^N = 0 \frac{P^{K_o}}{K_o!}} \quad (3)$$

where, P is the offered traffic (capacity), P_B is the blocking probability, N is the total number of traffic channels and K_o is number of users.

Call blocking probability

Call blocking probability (CBP) is one of the most important key performance measures of QoS in mobile communication networks. The QoS in any trunked system is often measured using a benchmark called the grade of service (GoS). The GoS is a measure of the ability of a particular user to access a trunked system during the busiest hour. The GoS is defined in several ways. In [14], GoS is defined as the number of unsuccessful calls relative to the total number of attempted calls. In ITU-T Recommendation E.800, GoS is defined by a number of traffic engineering variables to provide a measure of adequacy of a group of resources under specified conditions. In [15] GoS is described as the proportion of calls that are lost due to congestion that exists in the busy hour or probability of congestion or blocking probability, or probability that a call will be dropped due to congestion. The busy hour of a network is the time when the network processes the highest traffic in a day and it is used to measure network performance, determine the robustness of a network and its dimension. The CBP in any system should be minimized for better QoS. GoS is typically given likelihood that a call is blocked or the likelihood of a call experiencing a delay greater than a certain queuing time [16]. Minimizing the CBP is one of the main goals in terms of better QoS in cellular networks. The concept of traffic offered, traffic carried, and traffic lost illustrated in Fig. 1 [17] is used to conceptualize blocking probability (or GoS).

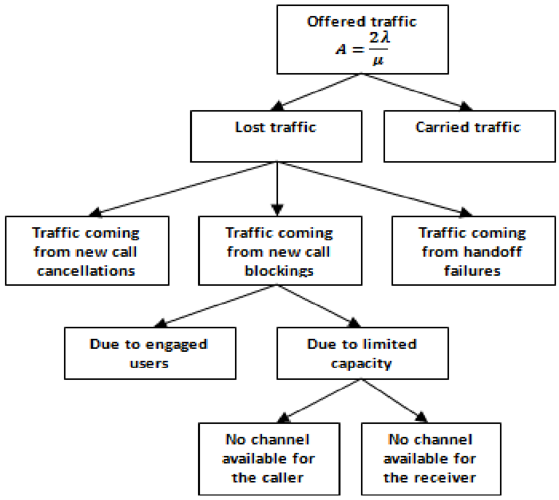

Figure 1: Network traffic scenario

The term grade of service is donated by P_B and it is defined in [18] as:

$$P_B = \frac{\text{Traffic lost}}{\text{Traffic offered}} \qquad (4)$$

In general, $GoS = P - A_O / P$

where, P = offered traffic, A_o = carried traffic and $P - A_o$ = lost traffic

The task of the teletraffic theory is to specify methods to ensure that the actual GoS is fulfilling the requirements. Thus, GoS is a subset of QoS and it is the mechanism for controlling the performance, reliability and usability of a telecommunication service. GoS is the traffic related part of Network Performance (NP), characterizing the ability of a network or network portion to provide the functions related to communications between users (ITU-T Recommendation E.800, 1994).

NP is measured in terms which are meaningful to the network provider and are used for the purpose of system design, configuration, operation and maintenance, and defined independently of terminal performance and user actions (ITU-T Recommendation I.350, 1993). The smaller the value of GoS, the better is the service. In any well-established network, a GoS is the acceptable performance benchmark of 2%. A GoS of 2% means that two calls in one thousand calls or one call in every five hundred calls may be lost. Technically NP is related to GoS [19] as:

$$\text{Network Performance}\,(NP) = \frac{1}{GoS} \qquad (5)$$

Therefore, from user's point of view, in order to improve the performance of a network, the value of GoS should be minimized, while from the network service provider's point of view, the objective is to decrease the cost of the network by increasing the utilization of the total available channels.

Spectrum efficiency

The evolution of data services is characterized by an increasing number of users with ever-higher bandwidth demands. As the wireless data market grows, deploying wireless technologies with high spectral efficiency is of paramount importance. Keeping all other things equal, including frequency band, amount of spectrum, and cell site spacing, an increase in spectral efficiency translates to a proportional increase in the number of users supported at the same load per user or, for the same number of users, an increase in throughput available to each user.

Increased spectral efficiency, however, comes at a price because it generally involves greater complexity for both user and base station equipment. Complexity can arise from the increased number of calculations performed to process signals or from additional radio components. Spectral efficiency, η_s describes how effectively a system can utilize, and the main goal of service provider is to accommodate maximum number of users in, the limited bandwidth. That is why spectral efficiency calculation plays very important role in wireless network planning, performance analysis, and optimization. It captures the fundamental tradeoff between the limited spectrum resource and the growing demands of broadband service, and is a critical parameter for all wireless networks in the planning and design. In general, η_s can be seen as a ratio between benefit (number of traffic channels, data rate) and cost (bandwidth). Numerous definitions for this ratio as have been presented in the literature by [20] and [21] includes: number of channels per cell, Erlangs/MHz/km^2, number of users/MHz/km^2, etc. Spectrum efficiency, η_s is usually analyzed, measured or simulated by means of some measuring units that produce system capacity as output. Another definition was suggested by [22]. This definition gives a more complete picture of the η_s by expressing it in terms of capacity, bandwidth, and area. If network capacity is evaluated using this method, it reflects the real situation of the network in the biggest cities where lack of available frequency resources is the highest. Thus the spectral efficiency can be defined as:

$$\eta_S = \frac{N_C \times P}{B_t \times A} \text{ Erlangs/MHz/km}^2 \quad (6)$$

where Erlang is a measure of the traffic load, in order to capture the frequency reuse in the service coverage area of the system, P = offered traffic per channel (Erlangs/channel), N_c = number of channels per cell, B_t = total system bandwidth (Hz) and A = area of service in km^2.

Equation (6) shows a simplified formula to estimate the required number of cell per square kilometer, (the offered load is in bits/second/km^2). As can be predicted from equation (6), increasing the η_s would improve the operator economics by reducing the number of cell per square kilometer.

In a mobile communication system, the spectrum efficiency can be enhanced by using various techniques such as choice of multiple access method, bandwidth reduction, resource allocation scheme, and the use of cognitive radio. Frequency reuse has been proposed to improve the spectral efficiency of radio systems that need to have reasonable cost and throughput services in networks growing very fast. The cell sizes, the ability of radio links to withstand interference, and the ability of the cellular system to react to variations in traffic are the main factors that determine the spectral efficiency of a cellular system [23].

A parameter named radio capacity in [21] is derived and used to measure the spectrum efficiency of a wireless system. The radio capacity of the omni cellular system is defined as:

$$m = \frac{B_t}{B_c K} \quad (7)$$

where m is the radio capacity, B_t is the total allocated spectrum for the system, B_c is the channel bandwidth, and K is the number of cells in a frequency reuse pattern. The factor Q is related with cluster size K in a hexagonal-shaped cellular system by:

$$Q = \sqrt{3K} \quad (8)$$

The co-channel interference reduction factor Q is obtained by;

$$Q = \left(\frac{D}{R}\right) = \left[6\left(\frac{C}{I}\right)\right]^{\frac{1}{\gamma}} \quad (9)$$

The value of C/I ratio is based on the required system performance and the specified value of γ is based on the terrain environment.

From equations (7), (8), and (9), the radio capacity is given as;

$$m = \frac{B_t}{B_C \frac{Q^2}{3}} = \frac{B_t}{B_C \left[\frac{6}{3^{\gamma/2}}\left(\frac{C}{I}\right)_S\right]^{\frac{2}{\gamma}}} \quad (10)$$

As shown by [21], in mobile radio environment, assume a fourth power rule, γ = 4, the radio capacity is given as:

$$m = \frac{B_t}{B_c\sqrt{\frac{2}{3}(C/I)_s}} = \frac{M}{\sqrt{\frac{2}{3}(C/I)_s}} = \frac{M}{K}(\text{freq. channels/cell}) \quad (11)$$

where $(C/I)_S$ ratio is the minimum required carrier to interference ratio. M is the total number of available voice channels. Equation (11) implies that the maximum radio capacity occurs when $(C/I)_S$ and B_c are minimized.

The total number of traffic channels M depends on the multiple access method. In GSM system which uses TDMA, Mt must be multiplied by the number of TDMA slots per carrier. In the case of GSM, the result would be $Mt = 8M$ traffic channels. The number of traffic channels is the same as the number of possible users since only one traffic channel is allocated per each user. With this extension to the traffic channels, equation (11) can be represented as:

$$mt = \frac{Mt}{K}(\text{Traffic channels per cell}) \quad (12)$$

The capacities of uplink and downlink are the same but are not comparable because uplink capacity is mainly related to number of users, and downlink capacity is related to transmitted power of base station. When the specified $(C/I)_s$ ratio is reduced, the radio capacity is increased. When the measured C/I is less than the specified $(C/I)_s$ ratio both poor voice quality and dropped call can occur. The above equation is obtained based on six co-channel interferers which occur in busy-hour (worst case) and describe the relationship between capacity, voice quality and dropped call rate. Radio capacity depends on issues such as service area, call duration, number of cells and total bandwidth. Equation (12) gives the relationship between the protection ratio and the number of cells per cluster needed for a satisfactory signal reception.

Carrier-to- interference ratio

Another parameter of interest to assess the cellular system performance is the carrier-to-interference (C/I) ratio. The ultimate objective of estimating this ratio in wireless systems is because it reflects user's throughput and quality of service. Therefore, computing the signal-to-interference ratio is important for determining coverage, capacity, and quality of service in a cellular system. The C/I ratio at the mobile is a random variable, affected by random phenomena as mobile location, fading, cell site location, traffic distribution, and others. The wideband Signal to Interference Ratio (SIR) is also called as Carrier to Interference (C/I) Ratio. The Carrier-to-interference ratio is very important in Cellular systems in order to determine the maximum allowed interference level for which the system will work. The more the C/I ratio is, the less co-channel interference we have and there is a room for applying a tighter reuse figure without loss of quality. The C/I ratio value should not be less than a certain threshold for more than 10% of the service area [24] and given as:

The mean $C/I = \gamma \log \sqrt{3K} - 10 \log I_o$ (13)

For the conventional cellular network systems other tier co-channel interference is neglected, which holds because frequencies are less than 2GHz, and cell size radii are 1.6 km (1mile), and above [25]. However, for emerging cellular communication system frequencies are greater than 2GHz and cell size radius are less than 1km [26]. The C/I ratio is expressed by:

$$C/I = 10 \log \left[\frac{1}{I_o} \times \left(\frac{D}{R} \right)^{\gamma} \right] \quad (14)$$

where, I_o is number of co-channel interferer (I_o = 6 in omnidirectorial antenna, 2 and 1 in sectoring cell (1st tier), γ is the propagation constant (γ = 4 in a cellular mobile environment), D is the frequency reuse distance which depends on many factors such as: the number of co-channel cells in the vicinity of the center cell; the geography of the terrain, the antenna height, the transmitter power within each cell and R is the radius of the cell. According to [27] the equation (14) may be written as:

$$C/I = 10 \log \left[\frac{\left(\sqrt{3K}\right)^{\gamma}}{I_o} \right] \quad (15)$$

K = frequency reuse factor (number of times a frequency can be reused in a network of cells). A high C/I ratio yields quality communication. A good C/I ratio is achieved in cellular systems by using optimum power levels through the power control of most links. When carrier power, is too high, excessive interference is created, degrading C/I ratio for other traffic and reducing the traffic capacity of radio system. When carrier power is too low, C/I ratio is too low and QoS targets are not met.

The formula determining the number of frequency reuse cells in a standard cellular configuration is obtained with γ =4 based on 40dB/dec propagation path loss [28]:

$$C/I = \frac{(D/R)^4}{6} = \frac{\left(\sqrt{3K}\right)^4}{6} = \frac{3K^2}{2} \quad (16)$$

or $K = \sqrt{\left(\tfrac{2}{3} C/I\right)}$ (17)

Different clusters lead to different re-use distances: a small cluster means that the distance between the users and the interfering cells is smaller. Therefore, the higher the re-use distance the higher the C/I ratio but less frequencies will be available per cell and the capacity will be smaller. Another way to increase C/I ratio is by reducing the number of interferers on the network, which can be done by using sectored cells.

The number of frequency reuse cells is a function of the required C/I ratio in a hexagonal cellular radio system that uses omnidirectional antennas**.** As soon as the C/I ratio decreases, the signal strength start deteriorating, thereby reducing the cluster size. Equation (17) confirms that smaller frequency reuse pattern is required to enhance spectrum efficiency performance.

Drop-call probability

Drop call rate (DCR) is the common term for describing the rate of calls which end due to technical reasons. There are different ways to calculate DCR. It can be calculated as dropped calls per Erlang, dropped calls over originated calls and dropped calls over all calls handled by each cell, including incoming handovers. It is usually preferred to use dropped calls over originated calls only, since it is the most common way in which operators calculate DCR. Furthermore, studying call dropping behaviors as a function of other network parameters (e.g. traffic load, utilization factor, call arrival rate and call duration) would aid the optimization of the system's performance and guarantee excellent quality of service delivery as well as improved revenue. Moreover, it is shown in [30] that the number of dropped calls due to inadequate radio link quality and other similar reasons is calculated from the relation:

$$\text{Drop-call rate} = \frac{\text{No. of dropped calls}}{\text{No. of call attempts}} \quad (18)$$

The probability of call dropping events is known as drop-call probability [29]. Drop-call probability is given by [30]:

$$P(Y = n) = \frac{(V_d t)^n}{n!} e^{-V_d t} \qquad n \geq 0 \quad (19)$$

Here, V_d is the drop-call rate, t the call duration, while Y is a random variable that counts the number of drops and n is the confirmed calls dropped. Call dropping events constitute a Poisson probability distribution function. For this model, there are no assumptions about a particular technology; it is worthwhile to note that the model can be exploited to predict the drop-call probability in different networks (e.g. GSM, PCS, UMTS). The drop-call probability is one of the most important QoS indices used to monitor the performance of cellular networks. Wireless service providers have to design the network to minimize the call dropping probability for customer care. Generally, more than 50% of the reasons for dropped calls by [31] in a cell, are reported to be mainly due to electromagnetic causes, and other factors are: the prepaid account balance, service plan subscribed, power supply of the mobile devices, the users' mobility mechanism, and handoff.

The application of the above formulae (equations 3, 18 and 19) in probability analysis as carried out in various literature [32] and [30] shows that dropped-call probability decreases with an increasing number of channels.

System coverage

An accurate estimation of path-loss is useful for predicting coverage areas of base stations, frequency assignment, proper determination of electric field strength interference analysis, handover optimization and power level adjustment [33]. Path-loss is defined as a decrease in the signal strength during propagation from the transmitter to the receiver [34]. Several effects may cause the path-loss, such as reflection, refraction, diffraction, absorption, propagation of signal over water, propagation of signal over vegetation (foliage loss), coupling, and cable loss [35]. The path-loss inside the building is also influenced by many factors, including the propagation medium, environment, height of the antennas, and the distance between the transmitter and the receiver inside the building [36]. In order to predict path-loss, the radio channels must be modeled [35]. Therefore, for practical path-loss prediction, propagation models are used. Path-loss is a function of the frequency of operation, the distance between the transmitter and receiver, terrain of operation, and system parameters like antenna heights and antenna characteristics.

Propagation path-loss models [37] play an important role in the design of cellular systems to specify key system parameters such as transmission power, frequency, antenna heights, and so on. Several models have been proposed for cellular systems operating in different environments (indoor, outdoor, urban, suburban, and rural). Some of these models were derived in a statistical manner based on field measurements and others were developed analytically based on diffraction effects. Each model uses specific parameters to achieve reasonable prediction accuracy. The long distance prediction models intended for macrocell systems use base station and mobile station antenna heights and frequency. On the other hand, the prediction models for short distance path-loss estimation use building heights, street width, street orientation, and so on. These models are used for microcell systems. When the cell size is quite small (in the range of 10 to 100 m), deterministic models based on ray tracing methods are used. Thus, it is essential to select a proper path-loss model for design of the mobile system in the given environment.

Propagation models [37] are used to determine the number of cell sites required to provide coverage for the network initial network design typically is based on coverage. Later growth is engineered for capacity. Some systems may need to start with wide area coverage and high capacity and therefore may start at a later stage of growth. The coverage requirement along with the traffic requirement relies on the propagation model to determine the traffic distribution, and will offload from an existing cell site to new cell sites as part of a capacity relief program. The propagation model helps to determine where the cell sites should be placed to achieve an optimal location in the network. If the propagation mode used is not effective in placing cell sites correctly, the probability of incorrectly deploying a cell site in the network is high. The performance of the network is affected by the propagation model chosen because it is used for interference predictions. As an example, if the propagation model is inaccurate by 6 dB (provided S/I 17 dB is the design requirement), then the signal-to-interference ratio, S/I, could be 23 dB or 11 dB. Based on traffic conditions, designing for a high S/I could negatively affect financial feasibility. On the other hand, designing for a low S/I would degrade the quality of service. Although no propagation model can account for all variations experienced in real life, it is essential that one should use several models for determining the path losses in the network. Each of the propagation models being used in the industry has pros and cons. It is through a better understanding of the limitations of each of the models that a good RF engineering design can be achieved in a network.

IV. EXPERIMENTAL DATA ANALYSIS

Data for this analysis were collected from a functioning 2G/3G/4G cellular network for six months in the frame work of Masters degree thesis. A total number of ten (10) Base transceiver Stations (BTSs) were covered. Also used were data from the Nigeria Communications Commission (NCC) to serve as benchmarks for the evaluation. The NCC is the statutory regulatory body for all operation in the telecommunication industry; in order to ensure uniform standards and quality service delivery to subscribers, they have specified benchmarks for compliance by each industry operation. The Quality of Service benchmark set up for network operators by NCC are presented in Table 1[38]. Benchmarking is a kind of assessment of the service quality of an operational network [39].

The primary (collected) data is presented in Table 2. These traffic parameters were used to determine the offered traffic, blocked traffic (traffic lost), traffic channels and other traffic performance parameters such as calls completion rate (CCR), call blocking probability, Channels utilization rate (CUR), drop-call rate (DCR), call arrival rate, drop-call probability, trunking efficiency etc. using (1), (5), (18), (19) and other traffic related equations in [30] and [40]. The results are presented in Tables 2, 3 and 4. However, in this analysis, the overall QoS of the network is evaluated using the trio of trunking efficiency, call blocking probability and drop-call probability. By improving these parameters, we improve the quality of the network. Call blocking probability and trunking efficiency are selected to serve for evaluating the network from the design point of view and; then drop-call probability is chosen as the most important to customer satisfaction from the utilization point of view.

Table 1: NCC key performance indicators benchmarks

S/N	Key Performance Indicator	Benchmark
1	Call Blocking probability	≤ 2%
2	Trunking Efficiency	≤ 60%
3	Drop-call Probability	≤ 0.01%
4	Carrier to Interference Ratio (C/I)	≥ 9dB
5	Spectrum Efficiency	1.36

Call blocking probability (also called grade of service), trunking efficiency and spectrum efficiency are parameters that are evaluated during the planning stage whereas drop-call probability is ascertained during the utilization phase of the network. Trunking efficiency and spectrum efficiency are correlated; both parameters are dependent on traffic intensity and number of channels (see equations (2) and (6)). Since the number of channels is normally fixed at design stage, it is only the variations in traffic intensity that will bring about a change in the values of trunking and spectrum efficiencies estimated at design. In other words optimization of the network is required after there is congestion brought about by increases in traffic intensity. Thus during performance evaluation, congestion is evidenced by the estimated levels of trunking and/or spectrum efficiencies if they are above the set regulatory benchmarks. Hence at this juncture, optimization is required which may be achieved by improving the trunking and/or spectrum efficiencies using various methods. As stated earlier, an improvement in trunking efficiency results in improvement in spectrum efficiency and vice versa depending on the selected GoS (call blocking probability). Drop-call probability on the other hand plays a central role in the performance evaluation of cellular networks. Generally, more than 50% of the reasons for dropped calls in a cell are reported to be mainly due to electromagnetic causes [31]. Thus it will be worthwhile to say that the techniques and strategies employed during the planning and design stage of the network are done so in order to reduce the occurrence of drop-call probability during the utilization phase. Thus if the estimated average drop-call probability is found to be too high relative the regulatory benchmark, then it means either the network was not planned and designed efficiently or there is congestion. Thus, the network will need to be optimized by checking and improving the other KPIs, especially coverage, trunking efficiency, spectrum efficiency and carrier-to-interference ratio.

Table 2: Operational data obtained from for 10 base transceiver stations

S/N	Base Station	Call attempt Based on (BHT)	Successful call Based On (BHT)	Call duration (s)
1	BTS1	7800	7796	103
2	BTS2	11104	10298	119
3	BTS3	5016	4936	34
4	BTS4	11871	11647	113
5	BTS5	2830	2799	22
6	BTS6	2124	2094	20
7	BTS7	928	922	28
8	BTS8	1123	998	103
9	BTS9	195	193	15
10	BTS10	370	362	114

Table 3: Analysis of trunking efficiency

Base Station	Number of Channel	Call attempts based on (BHT)	Calls Completed Based on (BHT)	Call Blocking Probability (%) $\frac{C-D}{C}$	Call completion rate (CCR) $\frac{D}{C}$	Offered Traffic in Erlangs	Carried traffic in Erlangs FxG	No of Dropped Call C – D	Trunking Efficiency (Utilization rate, %) $\frac{H}{B}$
A	B	C	D	E	F	G	H	I	J
BTS1	238	7800	7796	0.05	0.999	223.17	223.06	4	93.72
BTS2	400	11104	10298	7.26	0.927	367.05	340.40	806	85.10
BTS3	58	5016	4936	1.59	0.98	47.37	46.62	80	80.38
BTS4	400	11871	11647	1.89	0.98	372.62	365.59	224	91.40
BTS5	25	2830	2799	1.10	0.989	17.29	17.10	31	68.40
BTS6	19	2124	2094	0.94	0.991	11.80	11.69	20	61.53
BTS7	13	928	922	0.65	0.994	7.22	7.17	6	55.15
BTS8	42	1123	998	11.13	0.889	32.13	28.55	125	60.74
BTS9	4	195	193	1.03	0.99	0.81	0.80	2	20
BTS10	19	370	362	2.16	0.978	11.72	14.47	8	76.16

Table 4: Evaluation of drop-call probability

Base Station	No. of Call Attempt (BHT)	Call in duration (s)	Number of Channels	Channel Utilization Factor	Drop call rate In BHT (%)	Call Arrival Rate (Call/s)	Drop call probability (%)
BTS1	7800	103	238	0.94	0.05	0.54	4.46×10^{-5}
BTS2	11104	119	400	0.85	7.83	0.77	1.44×10^{-5}
BTS3	5016	34	58	0.80	1.62	0.35	41.10×10^{-5}
BTS4	11871	113	400	0.91	1.92	0.82	1.77×10^{-5}
BTS5	2830	22	25	0.68	1.11	0.20	20.69×10^{-5}
BTS6	2124	20	19	0.62	0.96	0.15	11.57×10^{-5}
BTS7	928	28	13	0.55	0.65	0.06	1.38×10^{-5}
BTS8	1123	103	42	0.61	12.53	0.08	0.015×10^{-5}
BTS9	195	15	4	0.20	1.04	0.01	9.56×10^{-10}
BTS10	370	114	19	0.76	2.21	0.03	6.08×10^{-5}

Analysis of trunking efficiency

The trunking efficiency performance of the network is presented in Table 3 and plotted in Fig. 2. It can be seen that the best performing base stations are 7 and 9 having the lowest trunking efficiency below the NCC benchmark. Base transceiver stations 2, 4, 1, 8 and 3 followed by 10, 5 and 6 trunking efficiencies is above 60% benchmark stated by NCC. These will result in loss of calls or blocked calls in affected base transceiver stations. Effort is therefore required by the mobile communication operator to improve this KPI and NCC should ensure that they conform to the benchmarks to avoid blocked calls during the busy hour. Thus appropriate optimization measures are required to increase capacity.

Analysis of call blocking probability

The call blocking probability performance of the network is shown in Table 3 and Fig. 3. It shows a bar chart displaying the call blocking probability level attained in each base transceiver station. It is observed from the chart that only base stations 1, 3, 4, 5, 6, 7 and 9 met the benchmark QoS of 2%. This means that the congestion experienced by the users in these base stations is low. Other base transceiver stations 2, 8 and 10 fail to meet this target and this could imply that congestion by the users in this subnetwork of the mobile network operator is high and so optimization is needed. As stated earlier, the congestion may likely be due to variations in the traffic intensity. Therefore, the optimization measures required may be to improve mainly the trunking efficiency and/or spectrum efficiency.

Analysis of drop-call probability

The drop-call probability is one of the most important parameter for assessing the quality of service (QoS) in a cellular network. The results of drop-call performance shown in Table 4 and Fig. 4 confirm that the network is performing satisfactorily. This is because the estimated values of drop-call probabilities were well below the NCC QoS benchmark of 0.01 at all the 10 base stations. This implies that the right path-loss models were used for the radio frequency design of system coverage and the radio propagation conditions of the traffic channels are fine. In fact, this fact is collaborated in our earlier work on this subject matter in [40].

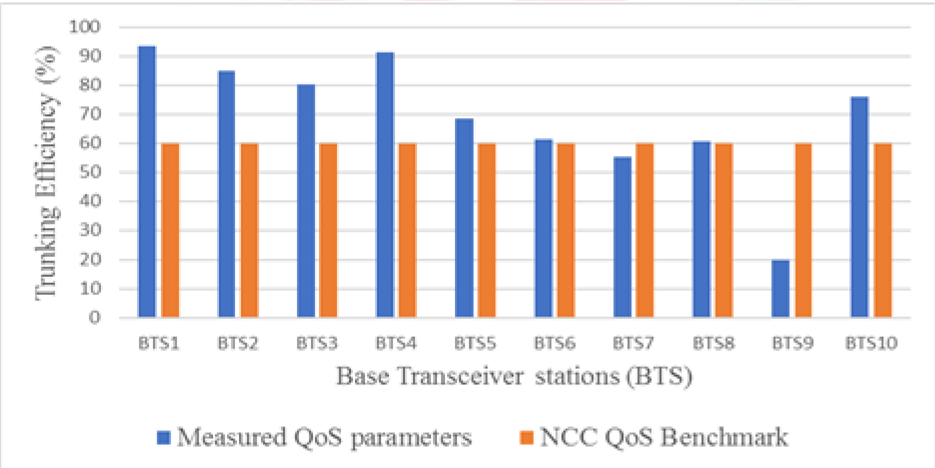

Figure 2: Comparison of estimated trunking efficiency with QoS benchmark

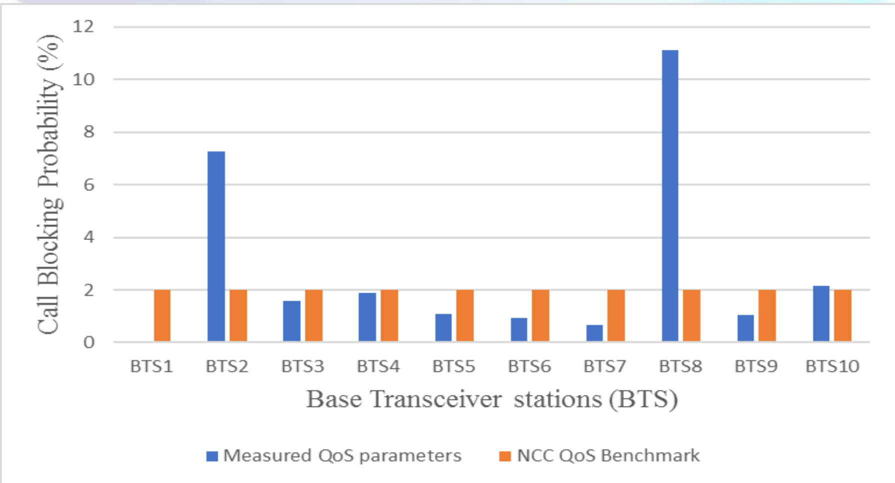

Figure 3: Comparison of estimated call blocking probability with QoS benchmark

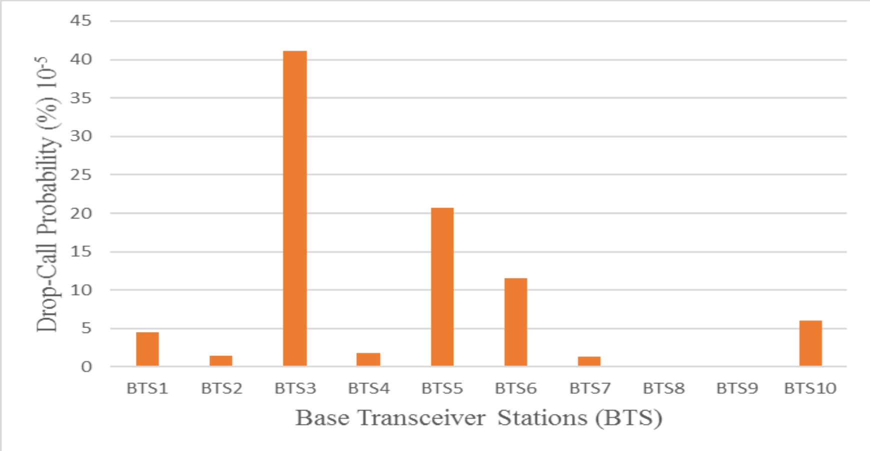

Figure 4: Comparison of drop-call probability at base transceiver stations

V. CONCLUSION

Monitoring the quality of service of any telecommunication network requires continuous processes that estimate the values of key performance indicators (KPIs) in real-time from analysis of the measured empirical data that determines quality of service rendered to the subscribers. Therefore, it is important for cellular network designers and service providers to have knowledge of the key performance indicators for the purpose of planning and optimizing the network usage and enhancing customer satisfaction [3]. Defining the KPIs is the most important part of the process because it relates to the methodology of optimization [4]. The KPI parameters are responsible directly for the coverage, capacity, and quality of the network. This informs the main objective of this paper, which is to provide comprehendible documentation about the key issues, involved in the study of key performance indicators. The coherent presentation of the general concepts coupled with the experimental data analysis performed to illustrate the application of KPIs for a live cellular network is aimed to realize this objective. It may prove worthwhile to adopt the data analysis methodology used in this paper for the performance evaluation of any cellular network.

REFERENCES

[1] A. Adegoke, I. Babalola and W. Balogun, Performance evaluations of GSM mobile system in Nigeria, Pacific Journal of Science and Technology 9(2), (2008), 436-441.
[2] Rizal Munadi, Fuzzy Logic-Based Mobility Management Scheme for Cellular Radio System, PhD, dissertation, 2011.
[3] B.M. Orstad and E. Reizer, End-to-end key performance indicators in cellular networks, Master's thesis, Agder University College, Norway, 2006
[4] A.R. Mishra, Fundamentals of Cellular Network Planning." Chicago: American Market Association, 2004.
[5] J. Isabona and I.G. Peter, Benchmarking mobile network quality of service with essential key performance indicators: a case study of operational GSM, 2014.
[6] J. J. Popoola, I.O. Megbowon and V. S. A. Adeloye, Performance evaluation and improvement on quality of service of global system for mobile communications in Nigeria, Journal of Information Technology Impact 9(2), 2009, 91-106
[7] R. C. Smith, and D. Collins, 3G wireless networks, 1st. New York: McGraw Hill TELECOM, 2006.
[8] Moray, IMT-Advanced: 4G wireless takes shape in an Olympic year, Agilent Measurement Journal, Nomor Research Newsletter: The way of LTE towards4G, 2008.
[9] E. Dahlman, S. Parkvall and J. Skold, 4G: LTE/LTE-Advanced for mobile broadband, Academic Press, UK, 2011.
[10] S.T. Rappaport, The cellular concept system design fundamentals, wireless communications, principles and practice, chapter 3, (Prentice Hall, New Jersey, 2002), pp 57-58.
[11] T. Zhang, and B.H. Soong, The effect of unreliable wireless channel on the cell performance in mobile network, accepted for publication in IEEE transactions on wireless communications. 4(2), 2005, 653-661.
[12] B. Chen, GOS and trunking efficiency (online), comlab.ecs.syr.edu/courses/ele751/files/**trunking**.pdf, Accessed, 29/08/19.
[13] S. C. Swales, M.A. Beach, D.J. Edwards and J.P. McGeehan, The performance enhancement of multi beam adaptive base-station antennas for cellular land mobile radio systems, IEEE Transactions on Vehicular Technology, 29(1) 1990, 56-67
[14] B. Nathan, G. Ran, and G. Freedman, Unified approach of GoS optimization for fixed wireless access, Vehicular Technology. IEEE Transactions, 51(1), 2002, 200-208.
[15] R. E. Farr, Telecommunications traffic. Tariffs and costs-an introduction for managers, Peter Peregrinus, 998.
[16] H. H. Hong, R. Malhamd and C. Gerarld, Traffic engineering of trunked land mobile radio Dispatneth system. Vehicular technology conference gateway to the future technology in Alotion; 41st 1CEE, 1991, 251-256.
[17] W.M. Tam, F.C.M. Lau, C.K. Tse, Y.X. Xia and M. Small, Traffic analysis of a mobile communication system based on a scale-free user network, International Symposium on Nonlinear Theory and Its Applications, (NOLTA2005), Bruges, 18-21 October 2005, 130-133.
[18] B.L. Cragin, Prediction of seasonal trends in cellular dropped call probability, IEEE, Capital City Applied

Research, Research Paper, 2375 Club Mredian Dr. #B7, Okemos, MI 48864, USA, 2006.
[19] S. Alagha, Queuing-based dynamic multi-guard channel scheme for voice/data integrated cellular wireless networks, M.Sc. Thesis, Eastern Mediterranean University, North Cyrus (unpubl), 2013.
[20] W.C.Y. Lee, Spectrum efficiency in cellular Networks, IEEE Transaction of Vehicular Technology, 1989, pp 975.
[21] F. Falciasecca, C. Caini, C. Riva and M. Frullone, General approach for comparison of spectrum efficiency of digital mobile radio systems, European Trans. Telecommun, 5, 1994, 77-83.
[22] M.S. Alouini and A. J. Goddsmith, Area spectral efficiency of cellular mobile radio systems, IEEE Transactions in vehicular Technology 48(4), 1999, 1047-1066.
[23] K. Murota, Spectrum efficiency of GMSK land mobile radio. IEEE Trans. Vech. Technol., 34, 1985, 69-75.
[24] M.D. Yacoub, Foundations of mobile radio engineering (CRC Press, Boca Raton, FL, USA, 1993).
[25] Mac Donald, Advanced mobile service: The cellular concept, The Bell System Technical Journal, 58 (1), 1979, 15-41.
[26] G. Hernandiez-Valdez, F.A. Cruz-perez, and D. Rodnriguez-lara, Sensitivity of the system performance to the propagation parameters in los microcellular environments, IEEE Trans. Veh. Tecnology, 57(6), 2008, 3488-3508.
[27] S. Ki Tae Kimo, A universal frequency reuse system in a mobile cellular environment, Vehicular Technology Conference (VTC), Spring, IEEE 65th, 2007, 2855-2859.
[28] Frequency reuse, (Online), http//www.iec.org, Accessed, February 6, 2016.
[29] E.O. Osunkwor, S.O. Atuba and O. Azi, Performance evaluation of well-established cellular networks using drop call probability analysis, International Journal of Scientific and Engineering Research, 4(6), 2013, 2342-2347.
[30] N.S. Tarkaa, M. Mom, C.I. Ani, drop call probability factors in cellular networks, International Journal of Scientific and Engineering Research IJSER, 2(10), 2011, 1-5.
[31] M. Ekpenyong and J. Isabona, modeling the effect of dropped calls on cell traffic in established 3g-based cellular networks. IEEE; 7 (2), 2014, 157-164.
[32] G. Boggia, P. Camarda and A. D'Alconzo, modeling of call dropping in well-established cellular networks, EURASIP Journal on Wireless Communications and Networking, Vol. 2007, Article ID17826, October, 2007
[33] A. Obot, O. Simon and J. Atolayen, Comparative analysis of path-loss prediction models for urban microcellular, Nigeria Journal of Technology, 30 (3), 2011, 50-59.
[34] Z. Nossire, J. Dichter, N. Gupta, J. Fathi, A new selected point to enhance radio wave propagation strength outside the coverage area of the mobile towers in the dead spots of cellular mobile WiFi downloads, In Proceedings of the 2015 Long Island Systems, Applications and Technology, Farmingdale, NY, USA, 1 May 2015, pp. 1–7.
[35] M. Alim, M. Rahman, M. Hossain, A. Al-Nahid, Analysis of large-scale propagation models for mobile communications in urban area. int. j. comput. sci. inf. secur 7, 2010, 135–139.
[36] T.L. Alumona, N.N. Kelvin, path loss prediction of wireless mobile communication for urban areas of imo state, south-east region of Nigeria at 910 MHz Int. J. Sens. Netw. Data Commun. 4, 2015, 1–4.
[37] Vijay K. Garg, An overview of wireless systems, in David Clark, M.I.T. (Ed), Wireless communications and networking, 1 (San Francisco: Morgan Kaufman, 2007), 1-16.
[38] Nigerian Communication Commission, QoS (Technical) Benchmarks for Mobile Services, (Online). Retrieved October, 2015, http://www.ncc.gov.ng.
[39] D. Soldani, M. Li, R. Cuny, QoS and QoE management in UMTS cellular systems. 1st ed. New York, NY, USA: Wiley, 2006.
[40] C.A.D. Pahalson, N.S. Tarkaa and G.A. Igwue, Method for analysis of system coverage and capacity for a GSM based cellular network, International Journal for Modern Trends in Science and Technology, 5(8), 2019.